

AN APPROACH FOR DETERMINING BIOLOGICAL INTEGRITY IN FLOWING WATERS¹

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Abstract.--Typical homogeneous ecological areas are determined by overlaying large scale U.S. maps of ecoregions, landform, soils, vegetation, land use, and river basins to find watersheds that best characterize as much of an ecoregion as possible. Typical stream reaches are selected from smaller scale maps and site visits and fish community structure is thoroughly analyzed to provide an assessment of the biological quality of streams.

BACKGROUND

The Nation's streams are routinely sampled for physical, chemical, and biological quality by many state and federal agencies. Yet, no clear national picture emerges about the biological condition of these waters. Physical and chemical data are not adequate to draw conclusions about biological conditions. Biological data are collected in many ways from a variety of locations using many different organisms resulting in much costly data that are difficult to interpret and lacks uniformity to make comparisons across the Nation.

The basic objective of the Clean Water Act of 1977 is "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." Since the law did not define integrity many interpretations of the term "biological integrity" have been made. None of them have been completely acceptable to EPA or the scientific community as a whole. Recently, EPA's Division of Monitoring and Data Support requested the Corvallis Environmental Research Laboratory to review the definition of biological integrity and how it might be monitored in the Nation's waters. A working group was assembled for this purpose and an integration and expansion of this

group's ideas are presented in this paper. The members of the working group were: Jack H. Gakstatter, Robert M. Hughes, and Thomas A. Murphy, (EPA-Corvallis), Lee Ischinger (FWS-Fort Collins), James R. Gammon and Michael D. Johnson (Depauw University), James R. Karr (University of Illinois), and Thomas M. Murray and Timothy S. Stuart (EPA-Washington, D.C.).

BIOLOGICAL INTEGRITY

Other work groups and symposia have attempted to define biological integrity and to suggest methods for its assessment (Ecology Committee, Science Advisory Board, USEPA 1980; National Commission on Water Quality 1976; Ballentine and Guarraie 1977). Usually, biological integrity is defined in terms of some base condition such as: (1) conditions existing before human colonization; (2) conditions that allow maintenance of indigenous, balanced populations; or (3) conditions found in existing ecosystems unperturbed by humans. Such base conditions refer to some pristine state that exists in relatively few ecosystems of the United States. Baseline "biological integrity" was interpreted in the U.S. Senate Committee on Public Works Report on PL 92-500 as being equivalent to pre-Columbian conditions of surface waters and this baseline was to be determined from historical records on species composition, ecological studies of the areas or comparable habitats, and modeling studies that estimate conditions of balanced, natural ecosystems based on the information available. However, accurate characterization of historically pristine ecosystems is impossible; even our knowledge of present conditions is inadequate for this purpose. Consequently, biological integrity of the Nation's

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waters from a pristine standpoint is unworkable, since it cannot be defined in practice.

For purposes of this paper, a definition of biological integrity has been adopted that establishes base biological conditions as those found in the least-disturbed typical reaches of large, relatively homogeneous faunal regions. Faunal regions group streams and rivers that would be expected to contain similar fish communities. This definition assumes that existing areas can be found that are sufficiently undisturbed to provide an appropriate reference. In regions where this is not possible it may be necessary to estimate base conditions from historical data or data from neighboring regions. Once these base biological conditions have been established, data gathered at other locations within faunal regions will be compared with the base to determine the relative well-being of each non-base location.

RATIONALE FOR USING FISH

The biological well-being or integrity of aquatic ecosystems can be estimated directly by examining all or some representative segments of aquatic communities. Murphy (1979)³ has discussed the advantages and disadvantages of biological monitoring. Experience has shown that physical and chemical characteristics of water cannot be used with certainty to predict whether or not biological integrity exists. One reason for this is that water quality characteristics are, to a large extent, time and flow dependent and water monitoring is rarely done on a continuous basis or during periods when water quality is at its worst. Also, it is virtually impossible to measure all of the possible chemical constituents in water that may affect biological integrity. Even if it were feasible, it would not always be possible to know how to relate chemical results to aquatic communities and their well-being.

One obvious advantage of using biological measures rather than physical or chemical measures is that biological conditions are determined directly. Another advantage is that aquatic organisms integrate and therefore reflect the total physical and chemical conditions in surface water systems over time. This is not to say that chemical and physical data should not be used to supplement biological measures, only that those surrogates alone are normally insufficient to predict biological quality.

Several approaches to field biological assessments have been employed in the past. These can be summarized as:

³Murphy, T. A. 1979. Biological monitoring. A concept paper. Office of Research and Development. U.S. Environmental Protection Agency. Washington, D.C. 13 p. mimeo.

1. Community level analyses: Sampling cross-sections of entire aquatic communities including fish, macroinvertebrates, aufwuchs, zooplankton, and phytoplankton.
2. Sub-community level analyses: Sampling one element of aquatic communities such as benthic macroinvertebrates, periphyton, or fish.

Community level studies produce a great deal of information about biological health but are not widely used on a routine basis because they are expensive and require considerable manpower, time, and individuals having diverse taxonomic expertise. Most monitoring and enforcement agencies do not have the resources to meet the level of effort required for a few studies each year let alone the widespread assessments necessary for a nationwide evaluation.

Sub-community level studies have been most widely used. Algae and benthic macroinvertebrate assessments have been most popular. For summaries of the pros and cons of these sub-community analyses see Hellawell (1977) and Hocutt and Stauffer (1980). Algae and macroinvertebrates include a wide variety of forms of varying sensitivity; they can be sampled easily and are abundant, allowing opportunities for replication and statistical manipulation. They exist in nearly all waters and have been used successfully for many years in water quality management programs. There are, however, several drawbacks to using them for rapid and broad assessments of biological quality: (1) specialized taxonomic expertise is required; (2) sample sorting and identification can be very time consuming and labor intensive; (3) the taxonomy of many genera and species is incomplete and not well-known; (4) macroinvertebrates and algae tend to be short-lived and microhabitat-dependent; (5) numbers of individuals and species usually fluctuate over several orders of magnitude in a short time and in a small area; and (6) the results are difficult to translate into values that have meaning to the general public.

Fish have been studied by fishery agencies for many years but have not been widely used in biological monitoring programs conducted by water pollution agencies. Assessing biological integrity based on fish communities is recognized to have some limitations: (1) fish are mobile and can move in and out of intermittently stressed waters; (2) sampling gear is relatively expensive and varies in sampling efficiency with fish species and life stage, season, stream type, time of day, and expertise of the collecting crews; (3) collecting fish is labor intensive; (4) year-class strength may fluctuate for natural reasons; and (5) some species are migratory and may only inhabit certain waters at certain times. While recognizing these limitations, there are a number of compelling advantages to using fish as indicators of environmental health or "biointegrity" (Hellawell, 1977; Hocutt and Stauffer, 1980; Funk, 1970). The advantages are: (1) com-

pared with other aquatic organisms, the environmental tolerances and competitive interactions of many fish are better known; (2) a number of trophic levels are normally represented in fish communities (i.e., carnivores, herbivores, omnivores) and their relative dominance provides insight into the quality of the community; (3) fish are dependent on other forms of aquatic life; therefore, the fish community can reflect the condition of the entire aquatic community to some degree; (4) the size structure of populations and the growth rates of individuals integrate the long-term effects of stressors; (5) many fishes in perennial warmwater streams are non-migratory; (6) nearly all fish species can be identified at the field site; (7) the general public can relate much easier to statements about conditions of the fish community than to any other segment of aquatic communities; (8) considerable inventory data on fish exist; and (9) the results can be directly related to the Congressional mandate of "fishable waters."

The value of using community structure to estimate characteristics of communities is based on considerable theoretical work (Menge and Sutherland 1976; Cairns 1974; Schoener 1974; Margalef 1963) and some empirical work with fish in stream ecosystems (Stauffer and Hocutt 1980; Gorman and Karr 1978; Stauffer et al. 1978; Hocutt et al. 1974; Tebo 1965; Katz and Gauvin 1953), and is a recommended approach by some for biomonitoring (Hocutt and Stauffer 1980; Alabaster 1977). An atlas of North American freshwater fish species with dot maps of distributions is now available (Lee et al., 1980). Methods for the sampling and analysis of fish communities are summarized in Lagler (1966) Weber (1973), Hocutt and Stauffer (1980) and Everhart et al. (1981).

GENERAL APPROACH

The approach proposed for the use of fish communities as indicators of biointegrity consists of the following key elements:

- Define boundaries of fish faunal regions.
- Define the areas within each faunal region that contain the land form, climate, soil, lithology, vegetation, land use and watershed characteristics most typical of that faunal region. Do not include atypical areas.
- Select control sampling locations in "least disturbed" reaches of each typical area.
- Sample fish and record observations at each control location.
- Establish a base of fish community characteristics for "least disturbed" control reaches for each area.

- Establish a rating scheme using base conditions found at control reaches as the highest level of biological well-being (biointegrity).
- Randomly select a number of test reaches within each area.
- Using the same sampling methods as for control reaches, sample fish and record observations for test reaches.
- Compare results of test reaches with control reaches (base conditions) and record the level of biological well-being for each test reach according to the rating scheme (relative biointegrity).
- Integrate results of all test reaches within a faunal region to arrive at an overall rating of biological well-being (relative biointegrity) for the region.
- At regular intervals (3-5 years) repeat the sampling and ratings to determine trends in biological well-being (relative biointegrity).

DEFINING FAUNAL REGIONS AND LOCATING SAMPLE REACHES

Ecological theory and methodology concerned with the spatio-temporal dynamics of several interacting ecosystems are poorly developed (Food and Agriculture Organization of the United Nations, 1980). However, Warren (1979) has explained why rational management of the Nation's streams depends on classification of watersheds and the regions that encompass those watersheds and he suggested a means of doing so. Fish distribution patterns among and within river basins will be used to define the limits of faunal regions. Field ichthyologists are knowledgeable about fish community structure and the distribution of species in nearly every state or region. These authorities can be consulted to determine major faunal regions that have a common habitat class and distribution of fishes. Generally, these major faunal regions will be very large, covering perhaps thousands of square miles and stream miles. It is roughly estimated that the United States could be covered by approximately 50 to 60 major faunal areas.

On the average, faunal regions will contain fairly similar fish communities. However, because these regions are so large, they will contain small areas with features that are very different from the norm. Thus, it is important to select sampling sites that represent the most typical conditions of the region. This can be done by defining the areas of each faunal region that have the most typical conditions representative of the total region - its "representative" areas. "Representative" areas can be selected for each faunal region using overlay maps of land

form, climate, soil, lithology, potential natural vegetation, land use, river basins, and ecoregions (Bailey 1976). The sizes of the representative areas will vary, but they should be selected so as to contain conditions characteristic of the major part of the faunal region. Unique and unusual stream habitats of a faunal region would be excluded from consideration in a representative area. The map overlay approach as discussed by Omernik et al. (MS) is considered the best and most economical way to select typical areas most representative of the huge faunal regions involved.

The representative areas will contain all sampling reaches to be monitored for a given faunal region. They will contain streams that have the greatest applicability to the region and that best represent major types and sizes of watershed/stream ecosystems of the region. A sampling framework based entirely on political units or randomly selected river reaches would not yield useful sampling sites unless preceded by such an analysis. Once a representative area has been selected, its representativeness should be confirmed by site visits or verification by ichthyologists familiar with local and regional conditions.

In selecting a representative area it is important that streams and rivers are included that best represent size and gradient conditions typical of the faunal region. Comparable-sized streams within a representative area should be determined from their watershed areas and mean annual discharges. However, from a practical standpoint, streams can be broken into three size groups based on sampling methods required during moderate flow periods: (1) small perennial streams that are generally sampled by wading; (2) intermediate-sized streams that require the use of a small boat or canoe for sampling or where one would be useful; and (3) major rivers that require a large boat for sampling.

Selection of Control Reaches

One of the problems that must be addressed in biological assessment is to determine the kinds and numbers of organisms that should be present in the biological system being studied. Before the concern about nonpoint source pollution, river studies frequently dealt with the effects of point discharges. Assuming that an entire river system was not grossly polluted by point sources, it was common practice to compare biological conditions downstream from a point of discharge to those upstream from that point and the latter was considered the control or baseline condition. This still is the approach of many water quality studies, but does not give a useful measure of biological quality throughout river basins that are impacted by point and nonpoint sources of pollution, channel modifications, and changes in riparian vegetation caused by man.

Control reaches within a representative area of a faunal region should be selected for each of the three size classes of streams discussed above. These control reaches must be selected at locations where there is a minimum of impact from man's activities, i.e., "least disturbed." Selection of control reaches is of critical importance because the fish community characteristics of these reaches will be used to establish baseline conditions (biointegrity) against which all similar-sized test reaches will be compared. If a particular faunal region has a sufficient history of fish studies, it may be possible to define baseline characteristics of fish communities without establishing control reaches. Such a decision would be made with advice from ichthyologists familiar with fish communities of the faunal region.

The selection of "least disturbed" control reaches must be done with the advice of scientists and water quality experts in the area who are knowledgeable about biological, physical, and chemical water quality problems. Evidence of stream captures, channel subsidence, and other natural factors affecting dispersion should be considered. The control reaches must be typical of the faunal region that they represent in terms of the local physical characteristics of the reach, such as channel structures, stream morphology, substrate, and instream cover. Field checks should be used to insure that the control streams or reaches are as free as possible from natural barriers such as major falls or drainage divides or from human impacts such as nearby bridges, highways, channel and bank modifications, significant upstream point sources, irrigation withdrawals and returns, and significant nonpoint source problems.

In large rivers and where land use is intensive, totally unimpacted reaches will be impossible to locate. Where least disturbed conditions are too disturbed to be considered practical for baseline conditions it will be necessary to synthesize base conditions from historical data or, possibly, from data of neighboring regions. A highly experienced ichthyologist must be used to synthesize base conditions. In the event base conditions cannot be synthesized because suitable data are unobtainable, least disturbed systems may have to serve as the basis for establishing base conditions, but their limitations for use as "least disturbed" must be documented.

Selection of Test Reaches

Once biological integrity has been defined in terms of fish community characteristics in typical, different-sized streams, the next step is to select test stream reaches. This is also an important step because the data obtained from the test reaches must be representative of the entire region to obtain a good estimate of the state of biological well-being relative to control conditions. The number of test reaches to be evaluated should reflect the size and diver-

sity of the representative area as well as the diversity of its point and nonpoint source pollution problems. An additional factor will be the amount of resources available to make test reach assessments.

Selection of test reaches within a representative area should be made through a random process. Random selection within a representative area is preferable to a random selection from all streams within a faunal region. This will help insure that the major types of streams will be examined at the fewest number of sites needed to characterize a faunal region in terms of its level of relative biological integrity. If the objective is to assess the relative biological integrity of a specific reach rather than an entire region, comparable test and control reaches may be selected with the scale of the reach versus the region in mind.

PROCEDURES FOR SAMPLING FISH

It is important to obtain a representative collection of the entire fish community except for larval fish. Although more collections would increase sampling accuracy and facilitate statistical analyses, for reasons of economy we suggest only one sample per reach per year. Sampling should be done in the daytime and when flows are low or moderate, water clarity is relatively high, and fish migrations are minimal. Within each representative area, data for least disturbed and test reaches should be collected within a relatively short time span and under similar flow conditions so that valid comparisons can be made. Fish migrations and schooling can distort sampling results. For this reason, it is important to obtain any information available from ichthyologists familiar with local fish migration and schooling patterns. A series of specimens should be preserved for each species encountered in a reach to confirm identifications.

Small to Intermediate Streams

Reaches sampled in small to intermediate-sized streams should be long enough to include a minimum of two riffle and pool areas and contain representative major habitats of the area, e.g., shoals, runs, undercut banks, and debris jams. Normally the reach will range from 0.1 to 1 km long. Whenever possible, the ends of the sampled reach should be blocked with nets to contain the fish; then the fish within the blocked reach should be collected, preferably using electrofishing gear, seine, or both. The same gear should be used at every reach sampled within a representative area to provide comparability of sampling. Usually at least three passes through each reach will be required. Generally, the last pass should capture no new species and less than 10% of the number of fish obtained in previous ones. Total catch should be recorded per unit of time and area fished.

Intermediate Streams to Large Rivers

For larger streams and rivers it will not be possible to block off a reach and fish sampling may be done with boat mounted shockers, seines, trap nets, gill nets, electric trawls, or purse seines. Fishing should be done for fixed periods of time and cover representative habitats along shorelines and debris jams and in backwaters, side channels, riffles and embayments. A reach may be from 2 - 10 km long depending on habitat diversity. Total catch should be recorded per unit of time and area fished. It is extremely important to be consistent in collection methods so that valid comparisons of samples between reaches can be made. Consistent collection methods are more important than collecting all species and sizes, particularly in large rivers. Standard methods of sample collection must be adopted before large-scale monitoring for comparative purposes is attempted.

DATA TO BE COLLECTED

Habitat Observations

Some qualitative measures of stream beds and banks should be recorded as standard procedures because changes in riparian conditions and stream morphology can have a significant impact on fish community structure. Standard fish collection forms should be used to record the percent of cobble, gravel, sand and mud; mean depth and width of riffles and pools; and instream cover. Velocity, clarity, and temperature should be quantified by using appropriate devices. The time of day, erosive potential of banks, the prevalent land use along and immediately upstream of the reach, and obvious water quality conditions (such as color or odor) should be recorded.

Fish Observations

The characteristics of fish communities that should be recorded for each stream or river reach follow:

1. Species richness: include the number of fish species and a list of those species in each reach;
2. Relative abundance of fish: include number and size of individuals of each species, maximum and mean weight for each species, estimates of ichthyomass and catch/unit effort, and population estimates of dominant fish (where possible);
3. Trophic structure and spawning habitat relationships: can be derived from #1 and #2 and will give a rough indication of whether the system is dominated by omnivores or herbivores, rock foragers or mud foragers, complex nest builders, or simple spawners, or has a balance of various fish guilds;

4. Size classes: contrast length/frequency diagrams for representative species of each trophic group to determine the relative abundance of all year classes and also to determine if major shifts in year classes have occurred;
5. External symptoms of disease or stress: categorize the presence of lesions, tumors, fin rot, parasitism, emaciation, or other external manifestations of disease or stress by percent of affected individuals of each species;
6. Abundance of regionally intolerant species: identify those species that are generally intolerant of significant perturbations found in the region, such as turbidity, sedimentation, or nutrient enrichment, and are among the first to disappear. These are often important food or sport fish or endangered or threatened species;
7. Abundance of regionally tolerant and ubiquitous species: identify those species that are generally tolerant of significant perturbations found in the region;
8. Presence and abundance of introduced species: the extent and dominance of introduced species such as carp or salmonids. This must be considered because of differences in introductions among sites, i.e., transportation across barriers;
9. Presence and abundance of obvious hybrids: note observations of obvious hybrids as a possible indication of reduced reproductive isolation resulting from the breakdown of physiological or environmental cues.

These observations of fish community structure and function are more meaningful than species lists or diversity indices alone and may more accurately reflect ecological conditions. Such observations focus on habitat, trophic and reproductive guilds, and size class distribution, all of which may fluctuate less than species diversity or species lists, and they allow for species replacement or changes in quality that less subjective evaluations ignore.

DATA INTERPRETATION

An experienced field ichthyologist is vital for supervising collection and interpretation of field data. A single ichthyologist must be responsible for interpreting all data collected from a given faunal region in order to assure that ratings of biological conditions are uniformly applied. The ichthyologist must judge the conditions found at test reaches relative to those at undisturbed or least disturbed control

reaches. The ichthyologist's assessment will consider the following conditions, as a group, for indications of disturbance (modified from Karr, in press; Tebo 1965; Katz & Gauvin 1953):

1. Decreases in species richness, density, biomass, catch per unit effort, and intolerant species.
2. Increases in tolerant species, introduced species, hybrids, morbidity, and emaciation.
3. Changes in guilds from specialists to opportunists (such as from piscivores to omnivores, sight feeders to scent-touch feeders, complex to simple reproduction, long-lived to short-lived species, swift water species to slow water species, and rock or vegetation foragers to mud foragers), and changes in population structures (from residents that include several age classes, but are dominated by adults, to those with essentially one age class or age classes dominated by juveniles).

The ichthyologist then rates the biological conditions of each test reach relative to control (base) conditions according to one of the following tentative categories:

- Excellent -- Conditions indicate minor human disturbance (fish community similar to least disturbed conditions)
- Good -- Conditions indicate moderate human disturbance (fish community consisting of fewer species and a small percentage of tolerant species)
- Fair -- Intermediate
- Poor -- Conditions indicate major human disturbance (fish community consisting of a small number of species and an extremely small percentage of intolerant species)
- Very Poor -- Conditions indicate severe human disturbance (fish community absent or consisting of tolerant species only)

Obviously, each of the categories must be defined with greater precision than indicated above in order to assure comparability of results between areas within a region and between regions. It is proposed that a numerical rating system, similar to Karr's (in press) be developed with ranges to define each category. Criteria and definitions relative to the indications of disturbance described above can be developed through further study and numerical ratings assigned to each condition of disturbance. Summation of individual numerical ratings will result in a score that allows classification into

one of the above categories, i.e., excellent, good, fair, poor or very poor. Conditions intermediate between categories may be rated as fair-poor, good-excellent, and so on. Guidelines for arriving at biointegrity ratings must be developed with great care by one or more widely recognized ichthyologists and field tested before region-wide or nationwide application of this approach can be made.

If pilot studies conducted by the U.S. Environmental Protection Agency during 1981 to 1983 demonstrate the feasibility of this approach, a nationwide assessment program should be organized rationally. Competent ichthyologists in universities, laboratories, and state and federal agencies could participate in site selection, sampling, and analysis. However, there should be a group of 5 to 10 ichthyologists to (1) direct the program, (2) insure that the assessment is carried out in the manner stated herein, (3) insure that changes that do take place are for ecological versus political reasons, and (4) integrate the reports of the regional ichthyologists. The group of ichthyologists should have a mandate similar to those of the committees that produced the Atlas of North American Freshwater Fishes or the List of Common and Scientific Names of Fishes from the United States and Canada. This is essential because a national research and monitoring program of this sort could easily flounder if driven by purely political considerations or if it lacks a consistent conceptual framework and research model.

COSTS

It is estimated that, on the average, data collection for each river reach would require about 6 man-days of effort plus an additional 4 man-days of work for equipment care, data processing, and travel for a total of 2 man-weeks per stream reach. It is possible to sample 2 to 3 small midwestern streams per day but could take 2 days to sample a 10 km reach of a large river. A reasonable estimate for one team is coverage of about 25 to 35 reaches each summer (3 months) with data processing and analysis in the off-season. The estimated cost per team per summer for salaries and per diem assuming the equivalent of a GS-9 or 11 crew chief and two GS-5 technicians would be approximately \$20,000 or \$600 to \$800 per sampled stream reach.

Costs to equip each field crew would be relatively modest since many universities and state and federal agencies already have most of the necessary gear. Depreciation or rent on major items and purchase of some supplies is expected to cost less than \$7,000 per field crew to sample 25 to 35 sites.

The number of stream reaches that need to be sampled to characterize the biological well-being of a representative area will depend on the characteristics of the area. If it is assumed that a representative area within a faunal region

requires sampling of nine reaches in each of three stream sizes, a total of 27 reaches would be sampled per area. For this number of reaches, single season costs for sampling, data analysis, and overhead would be approximately \$50,000. Assuming 60 regions in the Nation, a minimum cost estimate for one national biointegrity assessment would be \$3.0 million. Trends in the biological well-being of the Nation's rivers and streams could be determined by conducting an assessment every three to five years on a regionally staggered basis. While total costs may seem high, they would be considerably less than any other known technique for quantifying the relative biointegrity of the Nation's streams.

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APPENDIX I. A CASE STUDY

A more complete discussion of this case study has been submitted to the journal, *Environmental Management*, but a brief summary of the approach follows. The case study took place in the central United States. The mean annual precipitation, landforms, soil orders, potential natural vegetation, and land use of the ecoregions, and the predicted extremes in biological integrity of the streams used in the case study are shown in table 1. The locations of the sampling sites are shown in figure 1.

Table 1.--Broad patterns of the study ecoregions.

	ECOREGIONS				
	Oak-Hickory- Bluestem 2511	Bluestem 2531	Maple-Basswood- Oak-Bluestem 2213	Sagebrush- Wheatgrass A3142	Douglas Fir- Ponderosa Pine- Engelmann Spruce- Subalpine Fir M3113
\bar{X} Annual ppt. (cm)	90	70	75	35-45	63-67
Land Forms	85% irregular- smooth plains; 15% open low hills	75% smooth- irregular plains	60% irregular plains; 30% open hills	100% plains with high hills ¹	100% open high mountains ¹
Soil Orders	75% mollisols; 25% alfisols	98% mollisols	65% alfisols; 20% mollisols; 15% entisols	100% mollisols ¹	100% alfisols ¹
Potential Natural Vegeta- tion	45% oak hickory forest; 55% oak hickory forest- bluestem prairie mosaic	90% bluestem prairie	55% oak bluestem savanna; 40% maple-basswood forest	100% sagebrush steppe ¹	100% western spruce- fir forest ¹
Land Use	45% cropland; 30% cropland with grazing land; 25% crop- land, pasture, woodland and forest	92% cropland	75% cropland with pasture, woodland and forest; 20% cropland	100% grazed shrubland ¹	100% grazed forest and woodland ¹
Predicted Extremes in Bio- logical Integrity ²	Big Creek; West Fork Middle Nodaway River	Deer Creek; Little Sioux River	North Branch Sunrise River; Elk Creek	Stinking Gulch; Lay Creek	Service Creek; Smith Creek

¹The broad characteristics are only relative to the six watersheds studied in the upper Yampa River Basin in ecoregions A3142 and M3113.

²Based on substrate diversity and size.

Visual estimates of the dominant characteristics of the stream bottoms are shown in figure 2. The site on Tarkio Creek had a clay bottom; Service, Smith, and Fish Creeks were typical gravel and boulder-bottomed streams; the other 24 streams were sand-bottomed prairie streams. The streams with the coarsest substrate were predicted to have the highest biological integrity, those with the most silt and clay the lowest biological integrity.

A preliminary assessment of the biological integrity (quality) of the fish communities of the 28 sites is shown in table 2. Biological integrity was estimated from $Q'_N = [0 (T) + 0.1 (LT) + 1.0 (LI) + 10 (I)]/[T + LT + LI + I]$ where T, LT, LI, and I refer to the numerical densities of tolerant, less tolerant, less intolerant, and intolerant species. Relative tolerance was determined from Carlander (1966, 1977), Scott and Crossman (1973), Pflieger (1975), Smith (1979), and Lee *et al.* (1980). These ratings are only

preliminary and alternate ratings are possible. A ranking based on physical habitat seemed most useful because substrate is easily observed and provides insights into potential reproductive and foraging opportunities. Q' values calculated from numbers and weights were highly correlated ($r = 0.84$), so only Q' s calculated from numbers are shown.

Values for species diversity (H') calculated from numbers and weights and species richness were also highly correlated ($r = 0.83$ and 0.79) so only species richness is shown. Correlations among catch/effort/area, number of species, and Q' were low ($r = 0.04$ - 0.38).

The relationship between the extremes of substrate diversity and size and the biological integrity (quality) of the fish community was expected but the closeness between the two measures is encouraging for such a preliminary study.

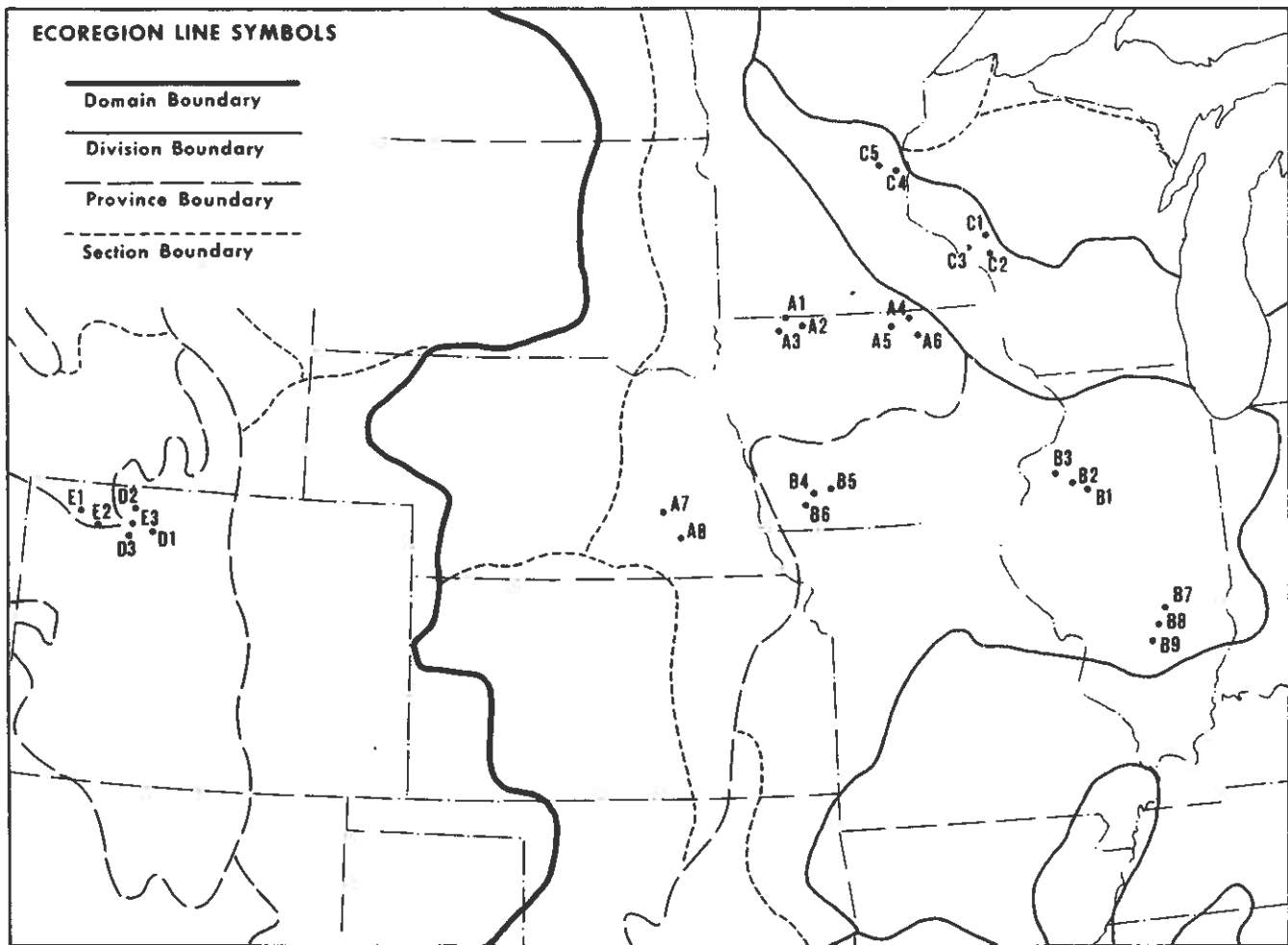


Figure 1.--Locations of study sites from which fish were sampled. The five different letters (A-E) that precede the numerals indicate the five different ecoregions we studied.

A1 Little Sioux	B4 West Nodaway	C3 Little
A2 Stony	B5 West Fork	Waumandee
A3 Big Muddy	Middle Nodaway	C4 Sunrise
A4 Deer	B6 Tarkio	C5 North Branch
A5 Elk	B7 Big	Sunrise
A6 Little Cedar	B8 Hickory	D1 Service
A7 Turkey	B9 East Fork	D2 Smith
A8 Swan	Kaskaskia	D3 Fish
B1 Indian	C1 Elk	E1 Lay
B2 Walnut	C2 Beaver	E2 Stinking
B3 Pope		E3 Foidel

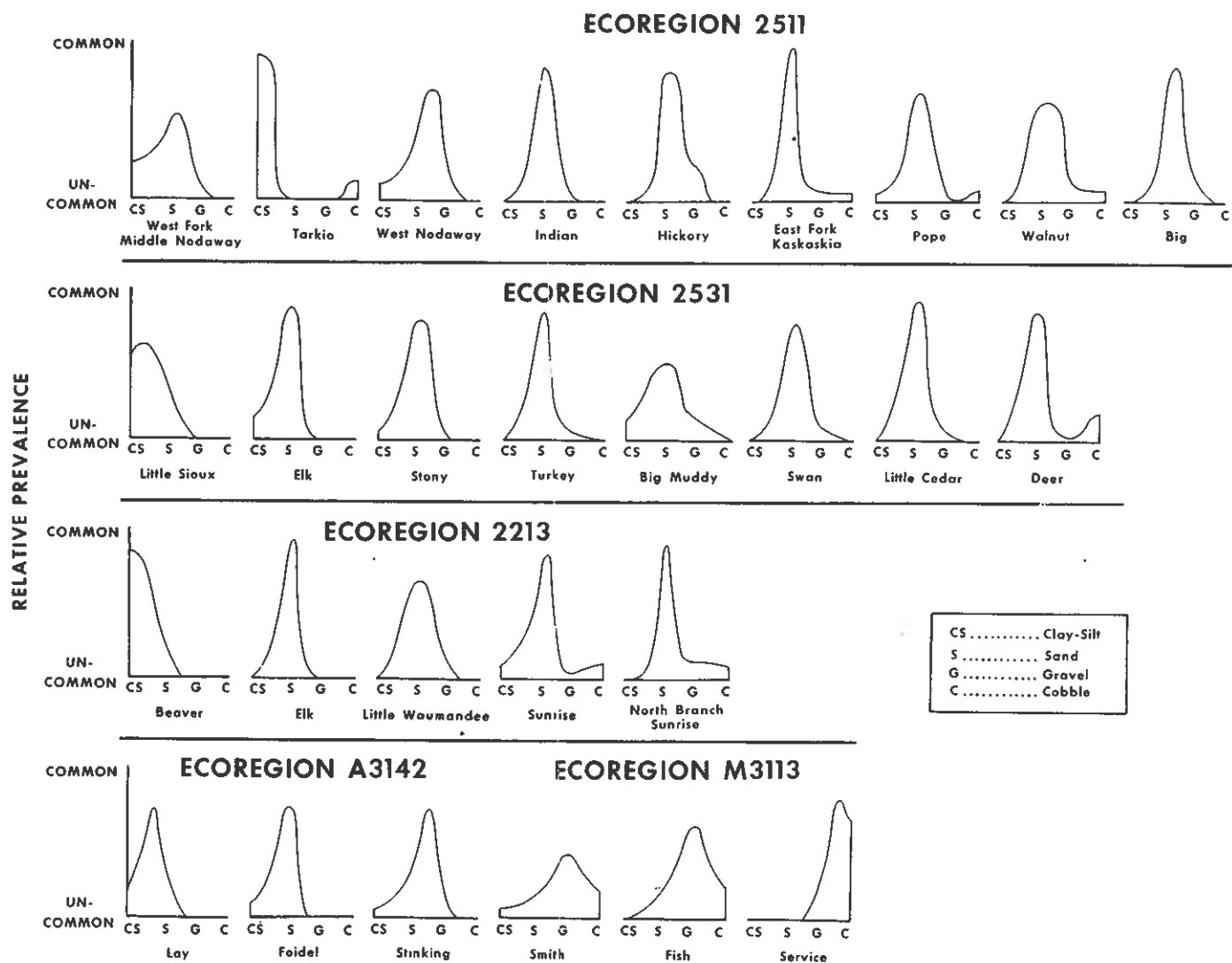


Figure 2.--Visual estimates of the dominant characteristics of the surface of the stream bottoms. The ordinate is based on percent cover and the area under all curves is equal. Stream reaches shown on the left of the figure have stream bottoms with lower substrate diversity or more silt and clay than those on the right.

Table 2.--Catch, species richness, and fish community quality of typical streams.

Stream ¹	Catch/Effort/Area		Number of Species	Q' N
	no/min/dm ²	g/min/dm ²		
<u>Ecoregion 2511</u>				
West Fork Middle Nodaway	5.9	10.2	9	0.05
Tarkio	23.5	8.1	5	0.06
West Nodaway	11.9	14.0	10	0.04
Indian	1.0	1.1	13	0.11
Hickory	3.2	8.4	16	0.18
East Fork Kaskaskia	1.6	3.0	15	0.24
Pope	0.1	0.9	14	0.85
Walnut	0.1	0.7	13	0.73
Big	0.9	1.6	19	0.84
<u>Ecoregion 2531</u>				
Little Sioux	8.5	8.5	12	0.01
Elk	0.1	0.4	8	0.47
Stony	0.3	1.7	13	0.21
Turkey	3.5	2.1	9	0.05
Big Muddy	4.5	36.0	17	0.74
Swan	1.3	7.9	10	0.22
Little Cedar	0.7	1.3	22	0.21
Deer	0.1	0.4	20	2.05
<u>Ecoregion 2213</u>				
Beaver	0.2	0.1	7	0.25
Elk	1.2	1.2	11	0.21
Little Waumandee	0.5	1.0	13	0.72
Sunrise	0.1	0.4	14	0.97
North Branch Sunrise	0.1	0.6	15	4.72
<u>Ecoregion A3142</u>				
Lay	0.9	0.6	1	0.00
Foide	0.5	0.6	2	0.06
Stinking Gulch	1.1	4.8	3	0.07
<u>Ecoregion M3113</u>				
Smith	3.1	4.8	3	2.62
Fish	1.0	6.6	2	10.00
Service	0.6	8.2	5	9.19

¹Streams in order of predicted biological integrity. The stream having the lowest predicted integrity in an ecoregion is listed first.